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Effects of CNC Tool Runouts on Drilling Process

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ABSTRACT

In this study, the surface roughness, dimensional accuracy and tool life that tool runout caused by CNC spindle mechanism based on metal mold manufacturing were investigated. In order to understand tool runout, spindle health measurement was performed: runout measurement with 300 mm test bar, spindle conical runout measurement, spindle pull force measurement and again spindle bearing vibration values were examined. In this study, spindle maintenance was performed and its effects on the final product before and after maintenance were investigated. Holes were drilled with 1, 2 and 3 times the drill diameter, the dimensional accuracy of the holes, the effect of runout on surface roughness in the hole drilling process and the runout and life of the drill bit used were investigated. The effects of runout before and after the maintenance were compared. Elimination of tool runout positively affected the surface roughness and parts with lower surface roughness were obtained. It positively affected the dimensional accuracy and the measurement tolerance was narrowed. Since the effect of tool runout on the cutting tool life is eliminated, its life is extended and the consumable cost is reduced. It has been observed that tool runout has a negative effect on machining in the hole drilling process with this experimental study.

Keywords: Tool Runout, Tool Life, Periodic Maintenance, Drilling

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1. Introduction

Drilling is a critical operation in addition to surface treatment during mould manufacturing, and it is an important machining step among many industrial metalworking methods. It has been reported to account for more than 40% of the processing rate in the processing of metals. [1]. The run-out that will occur in the tool in these operations is a phenomenon that significantly affects the tool life, geometric tolerances and machining costs and can cause significant financial losses if not taken into account. In drilling, the radial cutting force at the drill bit is critical to tool damage and ease of machining. Therefore, tool geometries are designed to reduce the cutting force. Run-out occurs when the rotating parts do not rotate axially in line. Run-out in drilling operations, that is, uneven cutting forces imposed on the tool edges, cause tool displacement, damage to the drill surface, and this leads to errors such as wear during boring and guide shafts working inside the hole [2, 3,4]. Tool run-out greatly affects the actual cutting radius of the tool; negatively affects the quality and efficiency of the processes. There are many simulations, models and studies on this subject; these operations enable cutting operations that lead to better surface accuracy, higher productivity and longer tool life [5]. Positional deviation of the spindle from the rotation axis during the drilling process can often be observed even at the beginning of the operation. This deviation is caused by the axial deviation of the tool rotation axis at the cutting edge. Experimental results show that drill protrusion length has a significant effect on hole position accuracy [6]. Matsumura et al. developed a force model to analyze drilling operations with cutter run-outs. In this developed force model simulation, three-dimensional chip flow in the drilling process is modelled by stacking orthogonal cuts on the planes containing the cutting and chip flow directions. With the force model presented, it was found that when the cutter run-out increased in the drilling of Aluminium (Al) pressure casting, the thrust decreased significantly [2].

Tool runout is triggered by not performing periodic maintenance of the cone, spindle bearings and drawbar springs that the tool is attached to on the spindle. These structures are shown in Figure 1. Periodic maintenance brings together many benefits such as production efficiency and longer use of the machine. [7].

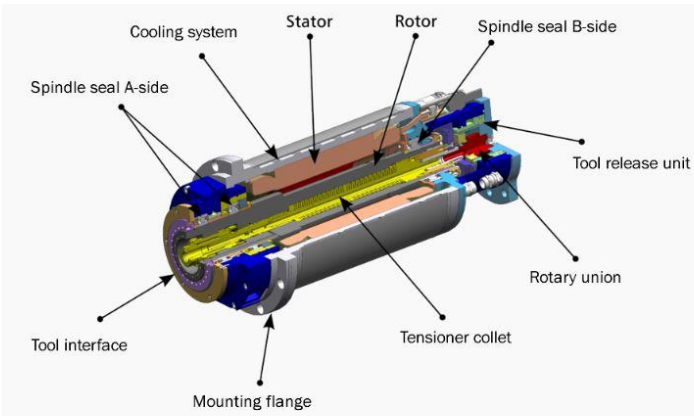

Figure 1. Appearance layout of CNC spindle parts [8]

The performance of a CNC machine tool depends on the accuracy of the machine to determine whether the end product conforms to the manufacturing specification. The accuracy of the machine must be measurable and analysable, so the effect of errors can be estimated on a workpiece. These errors can be eliminated by periodic maintenance and their effects on the final product can be minimized [9]. Considering the effect of spindle speed for cutter run-out, Zhang et al. proposed an effective non-contact calibration method and discussed the effect of cutter run-out on the mechanics and dynamics of the cutting process. The proposed models have been successfully validated by a series of experiments. Zhang et al., in their study, show that cutter run-out is dependent on spindle speed due to the variation of the vibration response of the spindle system under different spindle speeds [10]. An approach for modelling the milling process geometry with cutter run-out based on the actual tooth trajectory of the cutter in the milling process was proposed by Li et al. In these studies, it was observed that variable chip loads and variable wear on teeth were observed in evaluating the effects of cutter run-out using models [11].

The cutting tool run-out occurs in two different ways, radial and axial (Figure 2). Tool run-out is a phenomenon that affects geometry accuracy in the cutting process and is neglected in most of the studies on tool path planning. A new approach is presented for integrating the cutter run-out effect into envelope surface modelling and toolpath optimization for five-axis side milling with a tapered cutter. The results show that geometry errors caused by run-out can be significantly reduced by using the proposed method [13].

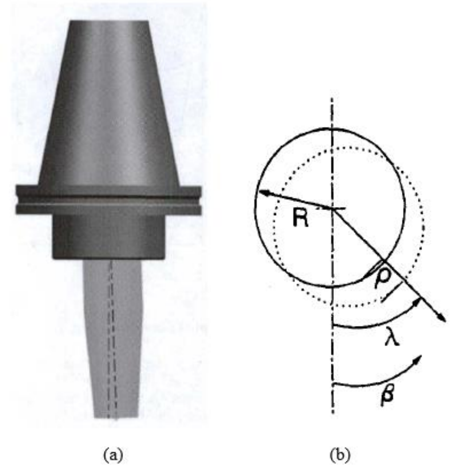

Figure 2. (a) cutting tool with axial run-out [13] (b) cutting tool path with radial run-out [14]

Run-out of the cutting tool has the effect of reducing the precision of defining the cutting forces parameters. Rivière et al. demonstrates the development of a given identification algorithm by modeling the radial run-out effect on the undeformed chip. With the help of simulation, both simple and complex models of the epidemic can predict shear forces [15]. A different approach has been made by Liang et al with a study on real-time chip load compensation to enable more efficient use of machine tools. In this study, the methodology they developed to eliminate cutting force oscillation and machined surface combs due to cutter run-out significantly improved the quality of machined surfaces by reducing their components in the spindle oscillation frequency, as well as the non-asymptotic stable dynamic factors of cutter run-out [16]. In the study using time dependent spectral analysis of shear force in order to estimate the shear run-out properties of force magnitude and angular orientation; The presence of cutter run-out and a cutting force component in the spindle rotation frequency also facilitates run-out monitoring [17]. In addition, mathematical models for cutting geometry, tooth radius, chip thickness, and entry/exit angles were developed by Kline et al. to examine tool run-out. These geometry models are combined with previously developed cutting force models to predict cutter run-out and cutting force characteristics for end milling process. It has been shown that the presence of run-out increases the average chip thickness for the cutting edge actually participating in the cut, it is also increasing the ratio of maximum force to average force [18]. Among the macro-to-micro effects of downscaling in size, tool run-out formation is an important factor that is affecting the cutting force, tool life, and surface integrity of the manufactured part. In conclusion, the precision analysis shows that spindle speeds of less than 5000 rpm in addition to lower run-out lengths guarantee angular errors in tool work [19].

The aim of this study is to create an experimental study on the extent to which the hole drilling operation, which constitutes 40% of the process during machining, affects the production efficiency the with effect of tool run-out and processing in accordance with the desired value after production.

2. Metarial and Methods

In the experimental study, SAE 1020 steel, which is widely preferred in construction body manufacturing and mould sets in the sheet metal forming sector, was used. The technical specifications of the steel are given in Table 1. With the experimental study to be made in terms of being suitable for surface hardening in the machining of steel and using it in the construction of apparatus and mould sets, the effect of the CNC spindle tool run-out on the hole during the hole drilling operation was investigated.

Surface roughness of tool run-out was measured with Mahr MarSurf PS1 model surface roughness device in a hole drilling operation with a length of 1, 2 and 3 times the drill diameter used in the hole operation; dimensional accuracy was measured with CMM (Coordinate Measuring Machine-Coordinate Measuring System) and its effects on drill wear were examined. The spindle specifications of the HAAS VM3 CNC vertical machining centre processed are given in Table 2. Coolant was used in the experimental study [20]. During the drilling operation, Oemeta brand coolant suitable for general and heavy machining was used. The properties of the coolant and the water used are given in Table 3. The drill bit, tool holder and boring parameters used at the same time are given in Table 4. Cutting parameters are given based on optimum machining conditions, adhering to the values in the product catalogue.

Table 1. Technical specifications of SEA 1020 steel

C	Si max	Mn
0.18-0.25	0.40	0.30-0.60
P max	S max	Sertlik (HB)
0,045	0.045	45-55

In the drilling operation, the effects on the drilling and chip formation during the process with the steel workpiece to be used in the experimental study, which was prepared to drill holes 1, 2 and 3 times the drill diameter, and the spindle with tool run-out were investigated. After the spindle maintenance, the process was repeated with the same processing parameters and material and compared.

Table 2. Spindle specifications of the HAAS VM3 machine

Spindle	Royal
Maximum Speed	12000 rpm
MaximumTorque	122.0 Nm @ 2000 rpm
Conical Code	CT / BT40

After the hole drilling processes, the dimensions of all the holes were measured in the CMM device. The dimensions of the entry-exit ends and the middle of the holes drilled 3 times the drill diameter and ovalities that may be caused by the run-out in the tool were observed. Then, it was cut from the exact axis of the holes with an electro-erosion device and the surface roughness was investigated. Following the drilling operation, the drill used was examined in terms of wear and tool life. These processes were repeated after the machine maintenance without the tool run-out.

Table 3. Coolant and its properties

Brand	Code	Emulsion Ratio (% Refract.)
OEMETA	Unimet 227	%5
Area of Use	Type	Water
General Machining	Semi-Synthetic	*Hardness = 15 °dH *Chloride = 57 ppm *pH = 7.7 *Conductivity = 665 µs/cm

Table 4. Cutting parameters

	f (mm/min)	S (rpm)
Parameters	50	1000
tool	Tool holder	Brand
HSSDIN 338/R-N Ø9.8 mm	Ball set	Machıne Tool

Drilling processes during the experimental study are shown in Figure 3 and Figure 4. Again, the tools and holders used during the work are shown in Figure 5. The wear of the drills used by the runout effect was investigated.

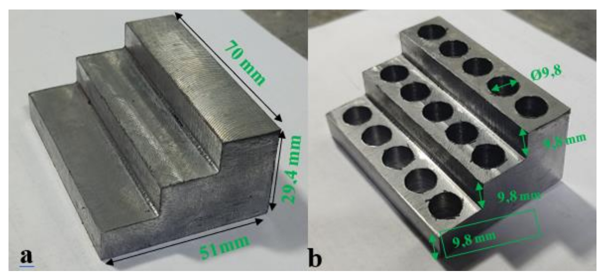

Figure 3. (a) Non-drilled test apparatus (b) Drilled test apparatus (Material SAE 1020)

Figure 4. Drilling operation of the test apparatus

Figure 5. (a) HSS drill Ø 9.8 mm (b) Ball holder and drill

3. Results and discussions

For lengths of 1, 2, and 3 times the drill diameter, pictures of the holes drilled before maintenance and with tool run-out are given in Figure 6. Drilling operations performed by removing tool runouts after maintenance are given in Figure 7. As the hole length increased in the holes drilled while the machine was run-out and not maintained, the burr structures formed in the hole also changed; burr images are given in Figure 7. As the hole length increases, the amount of burrs and burn marks due to overheating are observed in the metal.

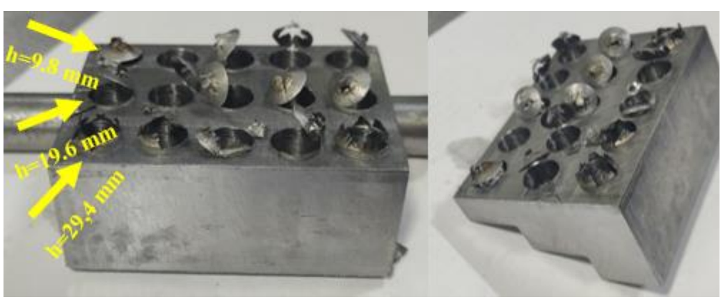

Figure 6. Burr formation that occurs according to the hole length that occurs in the drilled hole operation when there is tool run-out on the machine.

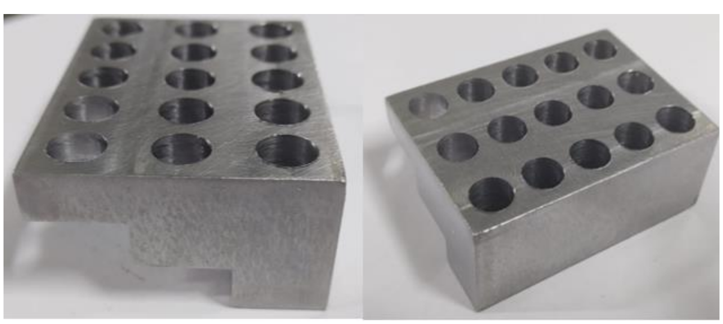

Figure 7. Hole exit images of drilled holes without tool runout after maintenance

After the maintenance, no significant burrs and burn marks were found at the hole exit points. No differences were observed in the holes according to the hole sizes. The structure of the holes resulted in the desired levels and in accordance with the production after the maintenance.

The hole diameter was measured from the middle of the top hole and the bottom of the hole with a CMM device after the hole operation performed while the bench was run-out before the maintenance. In these measurement results, the dimensions of the hole change in the upper, middle and lower sides. The average of the dimensions of the 5 holes drilled for each length before maintenance is shown in Table 5. The mean of measurements after maintenance work is shown in Table 6. Only the hole length h= 9.8 mm was not measured from the middle part because the length was short in the middle part of the hole. The diameter larger than the diameter desired to be drilled at the entrance of the hole has approached the desired diameter towards the end of the hole. The large amount of tool run-out at the hole entrance is due to the effect of axial forces that cause run-out, while minimizing axial forces with increasing hole depth causes the amount of run-out to decrease as the hole depth increases.It is gathered from this result that the drill spindle run-out changes the hole diameter. The fact that the holes are not suitable for the Ø 9.8 mm may cause problems that reduce production efficiency such as the loose fitting of the pins that can be used in production, the loss of centering of the moulds over time, the damage of the mould parts, the production of faulty parts due to the failure of their centre fit. After the maintenance, the measurement difference between the dimensions at the bottom of the holes and at the end of holes decreased from an average of 0.3 mm to around 0.01 mm, increasing the linearity of the holes. The degree of rigidity positively affects the life of the pins to be inserted into these holes.

Table 5. According to the hole lengths before maintenance, the average dimensions of the hole diameter at the top, middle and bottom of the hole

Hole diameter Ø	h=29.8mm	h=19.6mm	h=9.8mm
Hole entryAv.. Ø	10.118 mm	10.20 mm	10.158 mm
MidlleAv. Ø	10.086 mm	-	-
Hole exitAv. Ø	9.948 mm	9.974 mm	9.994 mm

Table 6. According to the hole lengths after maintenance, the average dimensions of the hole diameter at the top, middle and bottom of the hole

Diameter of Hole	h=29.8mm	h=19.6mm	h=9.8mm
Hole entry Av.. Ø	10.366 mm	10.358 mm	10.358 mm
MiddleAv.. Ø	10.365 mm	-	-
Hole exitAv. Ø	10.262 mm	10.282 mm	10.204 mm

Before the maintenance, that is, after the drilling operation performed while the machine is running, the diameter of the hole was measured in the middle of the top hole and the roughness Ra was measured with the surface roughness device from the bottom part of the hole. The roughness changes at the top, middle and bottom of the hole. The roughness increased towards the bottom of the hole due to the change in the diameter of the hole above and below the hole and the narrowing of the diameter under the hole. As the drill moves towards the bottom of the hole, it overheats due to the irregular tool friction forces that occur on the tool surface, especially on the cutting edges. With the increasing heat effect of the material at the bottom of the hole, the plastic behaviour that is facilitated due to the decreasing modulus of elasticity becomes more active, and with the increasing temperature, the cutting process turns into a chip removal mode with more shearing, and this increases the roughness.In addition, the decrease in the cross section of the sub-hole area, especially as drill bit approaches the bottom of the hole, and the increase in temperature make the plastic behaviour an active mechanism and easily deform with the drill advancing forces. Table 7 and Table 8 show the roughness averages of the 5 holes drilled before and after maintenance. Surface roughness measurements made after maintenance produced better results than before the maintenance.The measurement variables in the surface roughness were changed by approximately 30% as shown in the tables. As a result of the comparison of the pre-maintenance values, it is seen that the hole entrance dimensions are higher than the hole exit dimensions.

Table 7.Surface roughness measurements of the top, middle and bottom of the hole (Ra) according to the hole lengths before maintenance

Surface roughness (Ra)	h=29.8mm	h=19.6mm	h=9.8mm
Hole entry Av. Ra	0.8154	1.1454	-
MiddleAv. Ra	1.0146	-	1.3634
Hole exitAv. Ra	2.1544	1.5868	-

Table 8.Surface roughness measurements of the top, middle and bottom of the hole (Ra) according to the hole lengths after maintenance

Surface roughness (Ra)	h=29.8mm	h=19.6mm	h=9.8mm
Hole entry Av. Ra	0.7136	1.0476	-
Middle Av. Ra	0.9324	-	0.981
Hole exit Av. Ra	2.0718	1.1045	-

Due to the length of the hole, two measurements were taken from the hole with a length of h = 19.6 mm and a single measurement was taken from the hole with a length of h = 9.8 mm so that the surface roughness device could make a valid measurement. The surface roughness of the holes and the narrowing of the diameter from the top of the hole to the bottom can be seen in Figure 8.

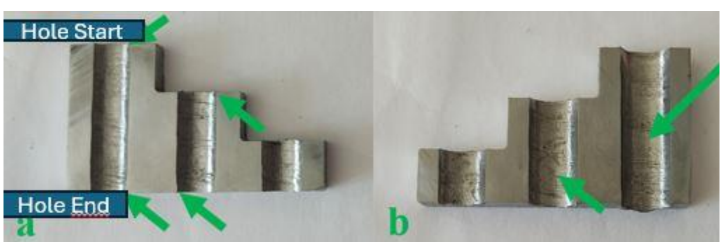

Figure 8.Drilling operation before maintenance; (a) Diameter changes at the top and bottom of the hole (b) Rough surfaces on the hole surface

The formation of the burr height that occurs during drilling when the tool is run-out due to the increase in the hole length can be seen in Figure 9. It was observed that the amount of burr at the bottom of the hole increased as the hole length increased. It is compared with the amount of burr formed after maintenance. Burr formation creates the need for more hand levelling and deburring operations. After the maintenance, no shrinkage or burr formation was observed in the hole.

Figure 9. Hole burr formation due to hole length when tool run-out is present before maintenance

4. Conclusions

In this experimental study, in which the effects of tool run-out on the drilling operation were investigated, tool run-out was measured before maintenance and maintenance was performed afterwards. In maintenance, after the maintenance of the bearings and the tension springs, the tool run-out was reduced from 45µm to 8 µm, as measured by the test apparatus, the spindle cone and the test apparatus, together with the conical grinding processes. As a result of the removal of tool run-out, machine efficiency has increased.

After the tool run-out has been removed:

• Surface roughness has improved %30 for hole entry, middle and exit compared to Tables 7 and 8.

• The hole size is produced with %35 less error when compared to the values in Tables 5 and 6.

• At the end of the hole, the burr formation seen in the pre-maintenance hole operation was improved by 20%,

• At the end of the hole, 40% of the surface color change due to heat generated during chip removal, which was observed during the hole operation before the maintenance, disappeared after the maintenance.

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Conflict of Interest Statement

The authors must declare that there is no conflict of interest in the study.

Author Statement

M. Kubilay Askerden: Conceptualization, Supervision, **Mustafa Yazar:** Conceptualization, Writing-original draft, **Şükrü Talaş:** Data curation, Validation

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